In 102 patients with angiographically proven occlusive carotid artery disease of 60–100% diameter reduction, Doppler ophthalmic artery pressure and blood flow direction were recorded by the recently developed ophthalmomanometry-Doppler technique. Among these 102 patients, 50 presented with complete carotid artery occlusions and 52 with carotid artery diameter stenoses of ≥60%. Mean±SD Doppler ophthalmic artery pressure was 69±15 mm Hg ipsilateral to the occlusion and 86±18 mm Hg ipsilateral to a stenosis of the carotid artery (p<0.001). The mean±SD Doppler ophthalmic pressure index (ratio of the ophthalmic artery to systemic blood pressure) was lower ipsilateral to the occlusion (0.46±0.08) than ipsilateral to a carotid artery stenosis (0.54±0.08; p<0.001); in both, the index was clearly diminished compared with normal values (0.68±0.04; p<0.001). It is concluded that the intracranial hemodynamic consequences in the patients with occlusion are on average more profound than in the patients with stenosis. In carotid artery occlusions, the mean±SD ipsilateral ophthalmic pressure index was 0.46±0.06 for antegrade and 0.46±0.09 for retrograde ophthalmic artery blood flow. In carotid artery stenoses, the mean±SD ipsilateral ophthalmic pressure index was 0.55±0.07 for antegrade and 0.48±0.06 for retrograde ophthalmic artery blood flow (p<0.01). These results indicate that in carotid stenoses the collateral capacity of the ophthalmic artery is insufficient compared with intracranial collaterals, while in carotid occlusions the blood flow direction in the ophthalmic artery does not predict intracranial hemodynamic compensation. (Stroke 1989;20:1012–1015)

The effect of significant occlusive extracranial arterial lesions on the intracranial arterial blood pressure and blood flow depends not only on the hemodynamic severity of the obstruction itself but also on the availability of an efficient collateral blood supply.1–3 Unfortunately, the circle of Willis is subject to considerable morphologic variation and differs among individuals in its functional efficiency.4

As the ophthalmic artery is the first large branch of the internal carotid artery, the study of the ophthalmic artery pressure (OAP) provides information about the amount of distal internal carotid artery blood pressure.1,2,5 Furthermore, examination of the ophthalmic artery flow direction in patients with occlusive carotid artery disease may help to detect the sources of collateral pathways.6 We recently developed a simple and safe method for OAP determination, called ophthalmomanometry-Doppler (OMD).7 Based on Doppler ultrasound principles, OMD provides simultaneous information about the maximum perfusion pressure and the flow direction in the ophthalmic circulation. In a previous paper,8 we validated this new OAP measurement technique and presented baseline data from normal subjects.

The purpose of our present study is to describe the findings of Doppler OAP and flow direction measurements in a series of patients with angiographically documented occlusive carotid artery disease of known severity, to analyze their hemodynamic disturbances, and to compare these results with normal data obtained previously in healthy subjects.

Subjects and Methods

We selected 102 patients (85 men and 17 women) aged 37–74 (mean 59) years who had undergone both bilateral OAP determination by OMD and subsequent carotid angiography. To be included in the study, the patients had to present 60–100% diameter obstruction of the carotid arteries prox-
mal to the off-branching of the ophthalmic artery, determined according to the criteria described by Alter et al. In most patients (95 of 102), good-quality conventional or intra-arterial digital subtraction angiograms (DSAs) were available in at least two planes, visualizing the extracranial supra-aortic as well as the basal cerebral arteries. In the other seven patients, only intravenous DSA of acceptable quality was available. The angiograms were analyzed by an independent radiologist who was not aware of the OAP measurement results. All OAP determinations were carried out within 3 days of carotid angiography without knowledge of the angiographic findings, and most OAP determinations were performed the same day as the angiography. Between OMD and angiography, all examined patients were in stable clinical condition.

All pressure measurements were performed with the patient’s head lying horizontally and after a rest period of 15 minutes in the supine position. Bilateral systolic OAP measurements were carried out with the newly developed OMD device (Figure 1). The instrument and the theoretical basis of the measurement procedure have been described in detail elsewhere. Briefly, the OMD device consists of a chamber, one side of which has an opening adaptable to the orbital borders. The opposite side is closed and equipped with a Doppler transducer and an inlet pipe for compressed air connected to a manometer. With the chamber fitted against the orbital borders, the Doppler probe is positioned over the medial frontal (supratrochlear) artery to detect the best Doppler velocity signal. Upon identification of the flow direction, a positive pressure is applied in the chamber while the Doppler probe continues detecting frontal arterial blood flow signals. The pressure within the chamber when the Doppler shift flow signal just disappears while increasing the pressure, or first reappears while reducing it, indicates the systolic arterial pressure in the distal ophthalmic circulation (Figure 1).

Measurements of the OAP by this indirect OMD technique simultaneously with direct intra-arterial recordings of the internal carotid artery pressure in 10 normal subjects with angiographically proven normal carotid arteries showed a strong relation between both systolic parameters, with a correlation coefficient ($r$) of 0.95. Immediately upon completion of the OAP measurement, we determined systemic systolic blood pressure by sphygmomanometer arm cuff and Doppler flow detector.

To compare patients with different central blood pressure values, the systolic OAP was expressed as a ratio of brachial artery systolic blood pressure (BAP), the ophthalmic pressure index (OAP/BAP). Statistical analysis of the ophthalmic pressure index, OAP, and BAP values in the groups of patients with occlusions or severe stenoses was performed by using the nonparametric Mann-Whitney test for two samples; $p<0.05$ was considered to indicate statistical significance.

Results

Doppler OAP measurements were completed routinely in all 102 patients without apprehension or discomfort. Among the 102 patients, 50 presented with complete carotid artery occlusions and the other 52 with carotid artery diameter stenoses of $\geq 60\%$. Sixteen of the 50 patients with occlusions (32%) and 10 of the 52 patients with stenoses (19%) had significant bilateral carotid artery disease.

The mean±SD and ranges for the values of OAP, BAP, and the calculated ophthalmic pressure index in all 102 patients with occlusive carotid artery disease are listed in Table 1. Ipsilateral to the occlusive carotid artery disease, mean systolic OAP was on average higher in the patients with stenoses than in those with occlusions (86 vs. 69 mm Hg, $p<0.001$). Mean systolic BAP was 157 mm Hg in the group with stenoses and 151 mm Hg in the group with occlusions. Thus, the mean ophthalmic pressure index ipsilateral to the occlusive carotid...
TABLE 1. Systolic OAP, BAP, and Ophthalmic Pressure Index in 102 Patients With Occlusive Carotid Artery Disease

<table>
<thead>
<tr>
<th>Disease severity</th>
<th>n</th>
<th>Mean±SD</th>
<th>Range</th>
<th>Mean±SD</th>
<th>Range</th>
<th>Mean±SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occlusion</td>
<td>50</td>
<td>69±15</td>
<td>45–120</td>
<td>151±23</td>
<td>110–230</td>
<td>0.46±0.08</td>
<td>0.26–0.60</td>
</tr>
<tr>
<td>Stenosis</td>
<td>52</td>
<td>86±18</td>
<td>45–125</td>
<td>157±19</td>
<td>110–190</td>
<td>0.54±0.08</td>
<td>0.34–0.69</td>
</tr>
</tbody>
</table>

OAP, ophthalmic artery pressure; BAP, brachial artery pressure; NS, not significant.

artery disease was substantially lower in the group with occlusions than in the group with stenoses (0.46 vs. 0.54, p<0.001).

Among the 50 patients with occlusions, the flow direction in the ophthalmic artery ipsilateral to the occlusive carotid artery disease was antegrade in 17, retrograde in 28, and equivocal in five. There was no difference in mean ophthalmic pressure index between the subgroup of patients with antegrade ophthalmic artery flow and the subgroup with retrograde flow (0.46±0.06 vs. 0.46±0.09; Table 2).

Of the 52 patients with stenoses, 41 presented with an antegrade, nine with a retrograde, and two with an equivocal flow direction in the ophthalmic artery. The mean ophthalmic pressure index was lower in the subgroup of patients with retrograde flow than in those with antegrade flow (0.48 vs. 0.55, p<0.01; Table 2).

Discussion

In a recent paper, we compared systolic OAP values determined by the OMD with simultaneously recorded direct systolic internal carotid artery pressure and indirect systolic BAP in healthy subjects; OAP correlates highly with ipsilateral intra-arterial internal carotid artery pressure (r=0.95, n=10) and with BAP (r=0.85, n=40). The mean ophthalmic pressure index (Figure 2) in both control groups (OAP vs. carotid pressure and OAP vs. BAP ratio) were almost identical (0.69 vs. 0.68).

The present study of 102 patients indicates that ophthalmic pressure index decreases in most cases of hemodynamically significant occlusive carotid artery disease compared with normal subjects (Figure 2). In the subgroup of 52 patients with stenoses, the ipsilateral ophthalmic pressure index overlapped with normal values in 15 (29%); in the subgroup of 50 patients with occlusions, however, ipsilateral ophthalmic pressure index in all but one patient was less than the lowest normal value (0.60). Ophthalmic pressure index in the normal subjects ranged from 0.60 to 0.77 and all were within the 95% confidence limit of the mean value of 0.68. Therefore, we consider a systolic OAP of <60% of BAP to be abnormal (Figure 2). This lower limit of the normal ophthalmic pressure index, as assessed by our OMD, compares favorably with the oculopneumoplethysmography (OPG-Gee) criteria advocated by Baker et al, by which an ophthalmic pressure index (OAP/BAP ratio) of <0.6 when no OAP asymmetry is present is considered abnormal. This is somewhat less than the lowest normal OAP/BAP ratio of 0.66 used by Eikelboom.3

The significant difference in mean ophthalmic pressure index between the subgroup of patients with occlusions and the subgroup with stenoses indicates that the intracranial hemodynamic consequences of the former are on average more profound than those of the latter.

TABLE 2. Ophthalmic Pressure Index and Direction of Blood Flow in Ophthalmic Artery Among Patients With Occlusive Carotid Artery Disease: Occlusion Versus Stenosis

<table>
<thead>
<tr>
<th>Disease severity</th>
<th>n</th>
<th>Mean±SD</th>
<th>Range</th>
<th>n</th>
<th>Mean±SD</th>
<th>Range</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occlusion</td>
<td>50</td>
<td>0.46±0.06</td>
<td>28</td>
<td>0.46±0.09</td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stenosis</td>
<td>52</td>
<td>0.55±0.07</td>
<td>9</td>
<td>0.48±0.06</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS, not significant.

FIGURE 2. Ophthalmic pressure index in control groups (A and B) and in subgroups of patients with occlusive carotid artery disease. Group A, normal subjects with direct intra-arterial carotid blood pressure measurement; Group B, normal subjects with indirect brachial artery pressure determination. Dotted line represents 95% confidence limits of combined control group A+B with patent carotid arteries.
not be explained by a higher prevalence of bilateral disease in the occlusion versus the stenosis subgroups (32% vs. 19%, $\chi^2=2.1$, $p>0.1$). Neither can it be attributed to a different occurrence of significant lesions of the ipsilateral external carotid artery ($\chi^2=0.6, p>0.3$). Therefore, the hemodynamic severity of the occlusive process itself seems to play a substantial role. Our results are in line with the OPG findings reported by Gee using a somewhat more difficult formula. However, in spite of the significant difference between the mean pressure indexes of both subgroups, there is a considerable overlap of individual values that precludes any attempt to assign an individual to either subgroup solely on the basis of the measured ophthalmic pressure index. Accordingly, to evaluate the degree of intracranial hemodynamic disturbance caused by significant occlusive carotid artery disease, individual determinations of OAP and the ophthalmic pressure index are necessary.

Furthermore, our study suggests that the hemodynamic significance of a change in blood flow direction in the ophthalmic artery differs depending upon whether the change occurs under conditions of carotid artery occlusions or carotid artery stenoses, a finding that has not to our knowledge been previously described. In patients with carotid artery occlusions (in our study 56% presenting with retrograde and 34% with antegrade blood flow), the ophthalmic artery blood flow direction does not seem to predict the degree of hemodynamic compensation. Accordingly, intracranial collateral pathways such as the circle of Willis are as efficient as extracranial-to-intracranial anastomoses via the ophthalmic artery (ophthalmic pressure index of 0.46 in antegrade as well as in retrograde flow direction). Contrary to this, in patients with significant (>60%) carotid stenoses (17% presenting with retrograde and 79% with antegrade flow) the collateral capacity of the ophthalmic circulation seems to be insufficient compared with intracranial collateral pathways (ophthalmic pressure index of 0.55 vs. 0.48 in antegrade vs. retrograde flow, respectively). A possible explanation may be the time factor. In patients with carotid artery occlusions and a longer disease history, extracranial-to-intracranial collaterals via the ophthalmic artery may enlarge, with time becoming as efficient as a functional circle of Willis.

Doppler ophthalmic pressure measurement is a simple and practical adjunct to rapid assessment of the degree of intracranial hemodynamic disturbance in occlusive carotid artery disease. OMD alone or together with transcranial Doppler studies may help to identify those patients who could benefit from carotid endarterectomy.

References


**KEY WORDS** carotid artery diseases • hemodynamics • ultrasonics
Doppler ophthalmic blood pressure measurement in the hemodynamic evaluation of occlusive carotid artery disease.
A L Strauss, H Rieger, F J Roth and W Schoop

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